Development of Radiation Resistant Quadrupoles Based on High Temperature Superconductors for the Fragment Separator

Ramesh Gupta
Superconducting Magnet Division
Brookhaven National Laboratory
Upton, NY 11973 USA

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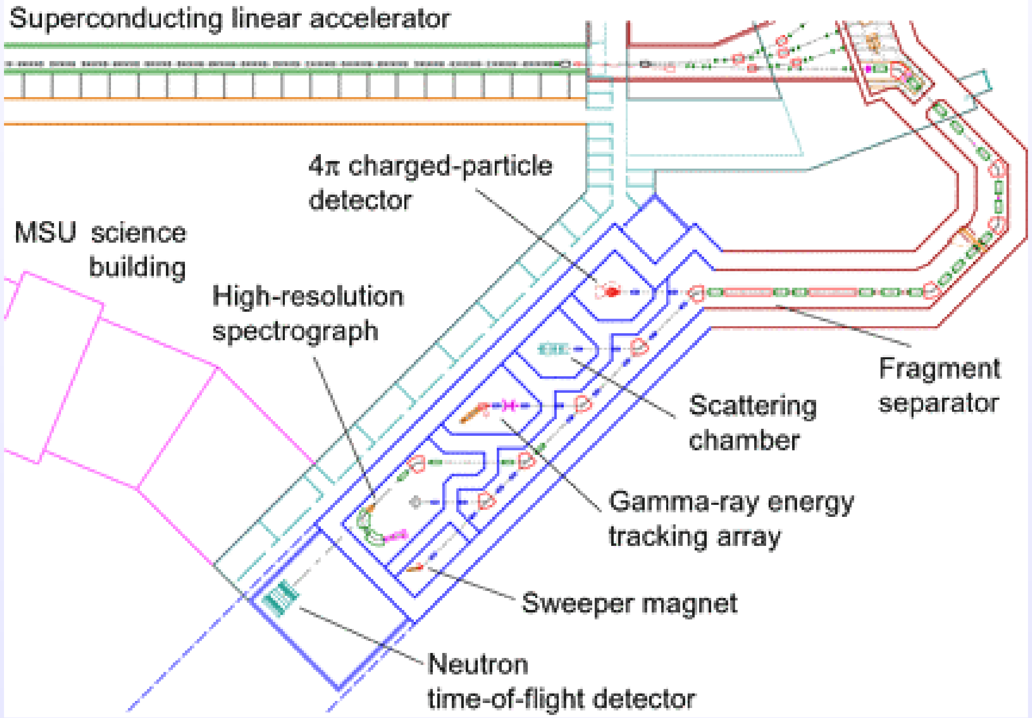
Fragment Separator Region of RIA

Magnetic elements (quads) in fragment separator region will live in a very hostile environment with a level of radiation and energy deposition never experienced by any magnet system before.



- Beam loses 10-20% of its energy in production target, producing several kW of neutrons.
- Quads are exposed to high radiation level of fast neutrons.

Room temperature, water cooled copper magnets produce lower gradient and/or lower aperture, reducing acceptance and making inefficient use of beam intensity.

Basically, we need *"radiation resistant"* superconducting quads, that can withstand large heat loads. There are many short and long time scale issues!

Short Time Scale Issues

Conventional low temperature (e.g. NbTi) superconducting magnets will quench if a large amount of energy is dumped on coils (> several mJ/g).

In addition, there is a large constant heat load on the cryogenic system : ~ 1 W/kg to the cold mass.

- The temperature increase must be controlled within the tolerances of the superconductor used.
- The large amount of heat deposited must be removed economically.

- HTS appears to have the potential of offering a good technical and an economical solution with the critical current densities that are available today. Of course, we can always do better with higher J_c.
- However, we need to develop technology and prove that this remarkable benefit can be utilized in a magnet system in the given environment.

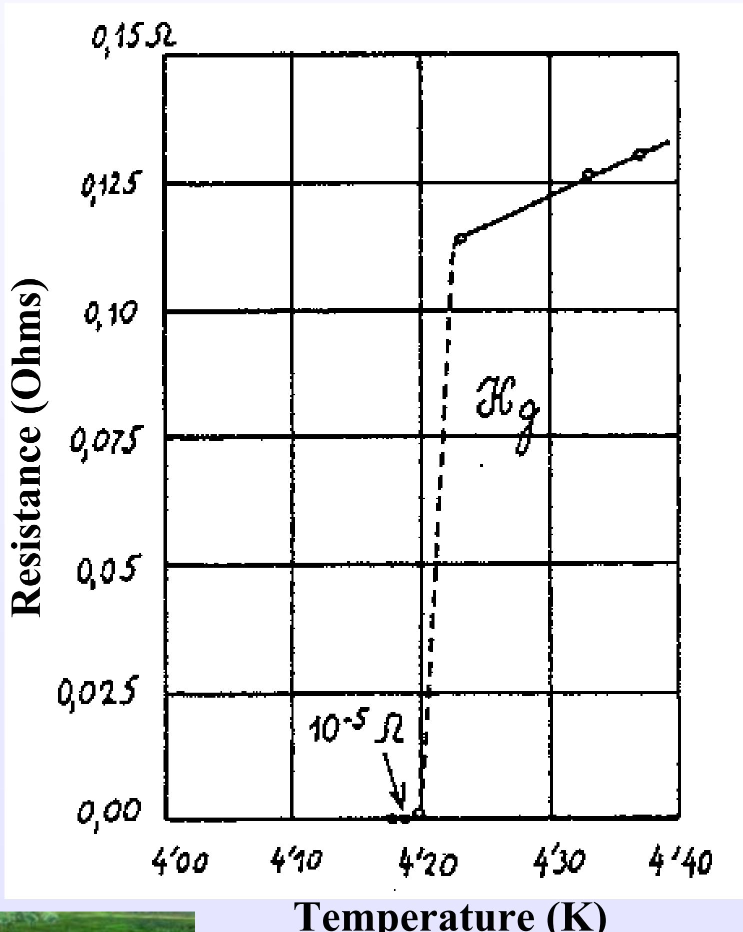
The Conventional Low Temperature Superconductors (LTS) and the New High Temperature Superconductors (HTS)

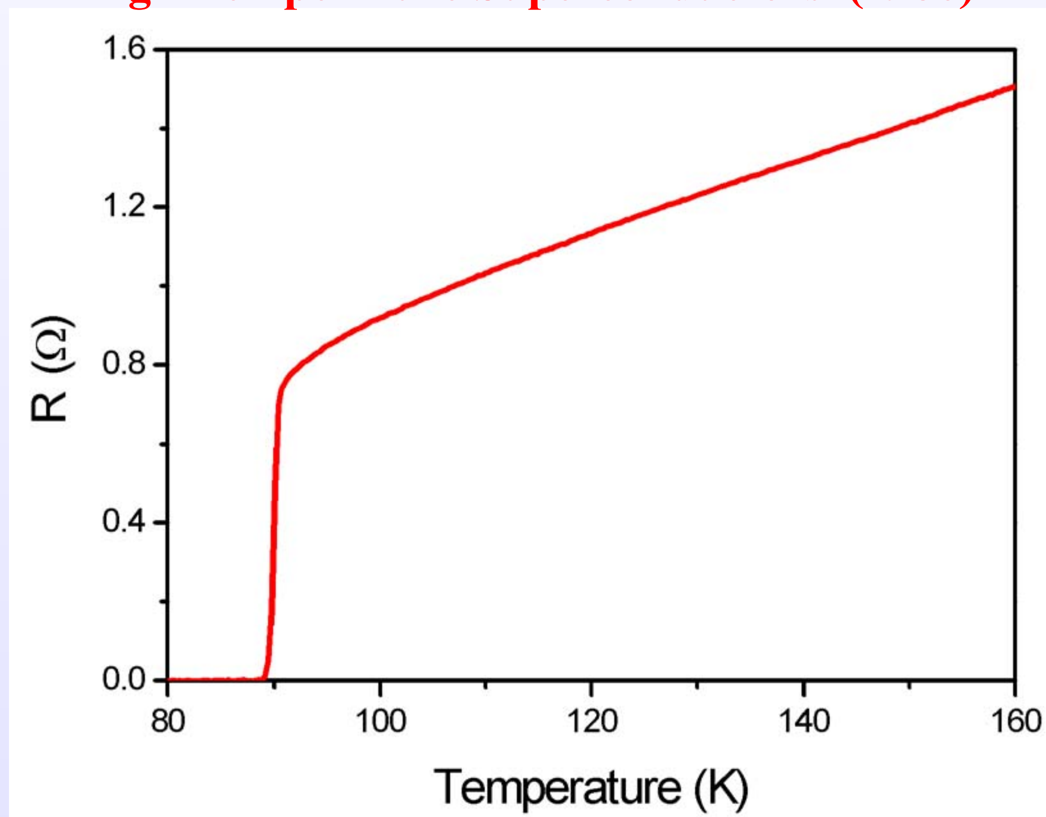
Low Temperature Superconductor Onnes (1911)

Resistance of Mercury falls suddenly below meas. accuracy at very low (4.2) temperature

New materials (ceramics) lose their resistance at NOT so low temperature (Liquid Nitrogen)!

High Temperature Superconductors (1986)



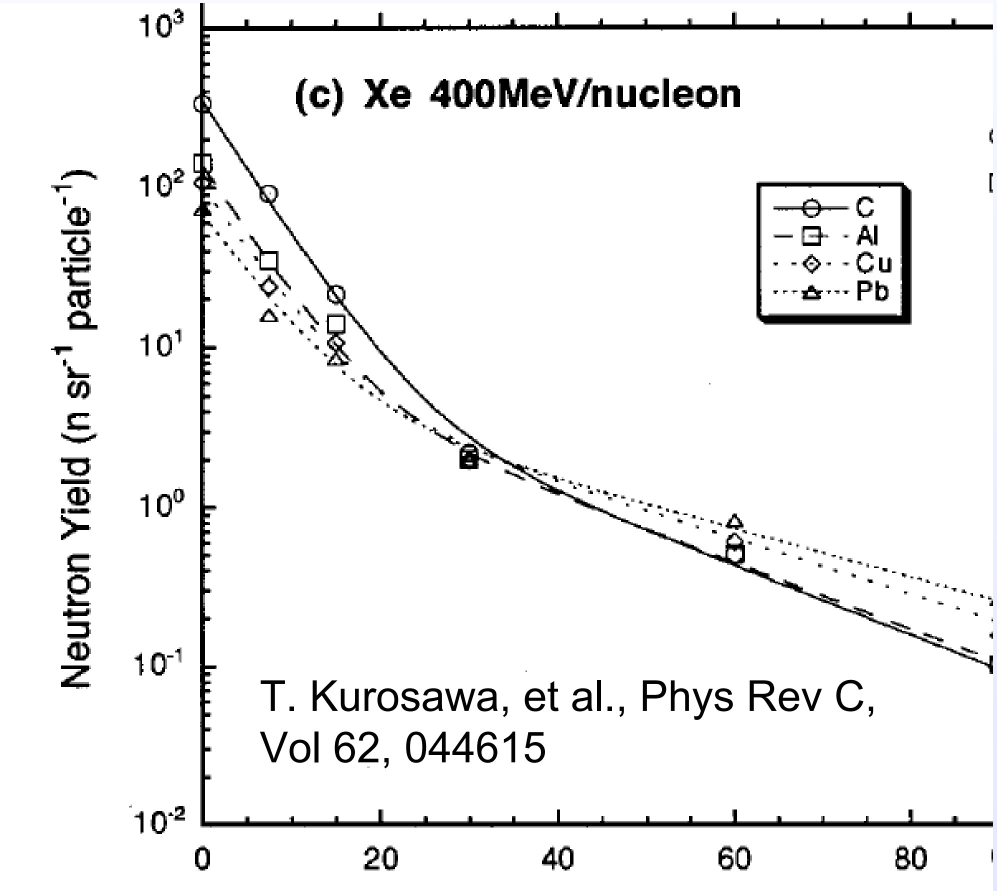


Advantages of using HTS in Magnets for Fragment Separator

- As compared to the conventional Low Temperature Superconductor (LTS), the critical current density (J_c) of High Temperature Superconductor (HTS) falls slowly as a function of temperature.
- The magnet system benefits enormously from the possibility of magnets operating at elevated temperature (20-40 K instead of conventional ~4K).
- HTS can tolerate a large local increase in temperature in superconducting coils caused by the decay particles.
- Moreover, the temperature need not be controlled precisely. The temperature control can be relaxed by over an order of magnitude as compared to that for present superconducting accelerator magnets.

Significant Reduction in Neutron Fluence at Larger Angle

BNL/MSU collaboration



T. Kurosawa, et al., Phys Rev C, Vol 62, 044615

The plot on the left shows a typical neutron dose as a function of angle, away from the target.

One must look at the impact on the material properties of such a high radiation dose over the magnet life time.

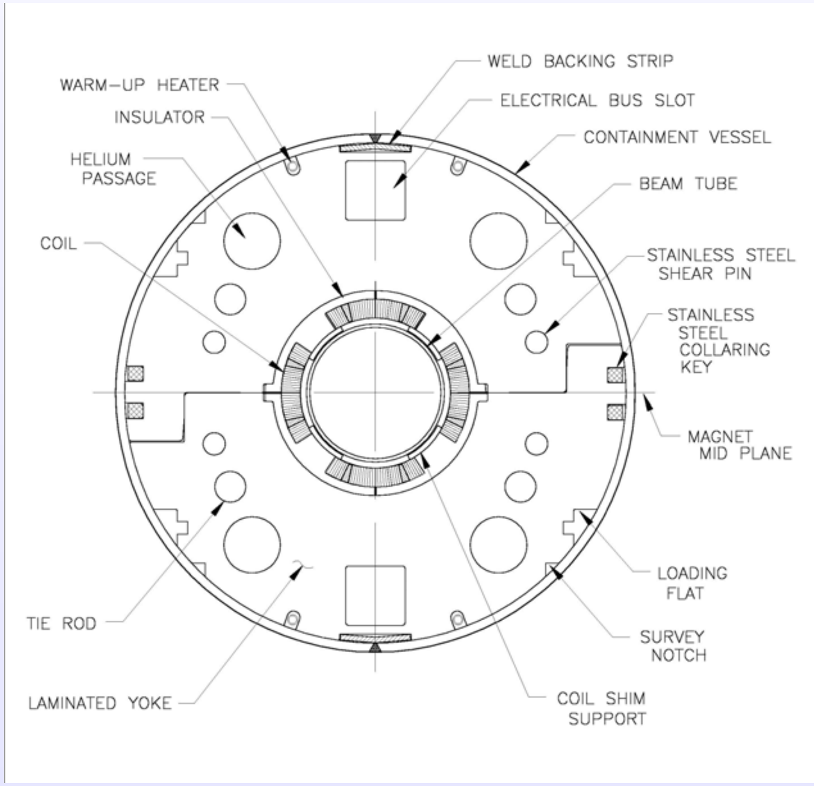
Estimated value in ~12 year period:

10^{19} neutrons/cm^2 in 0^o to 30^o region.

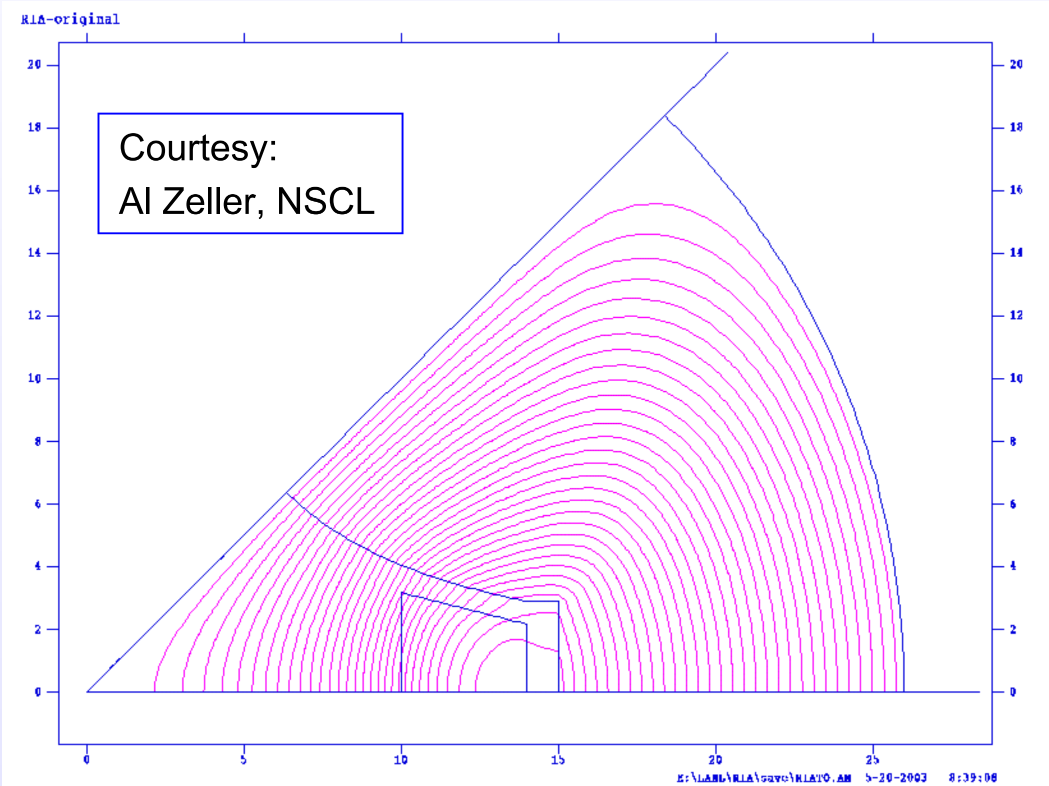
Note: Log scale and 50 X difference in value between 0^o and 30^o

Conventional Designs of Superconducting Quadrupoles for Fragment Separator

A Cosine theta Design with NbTi (LTS) Superconductor



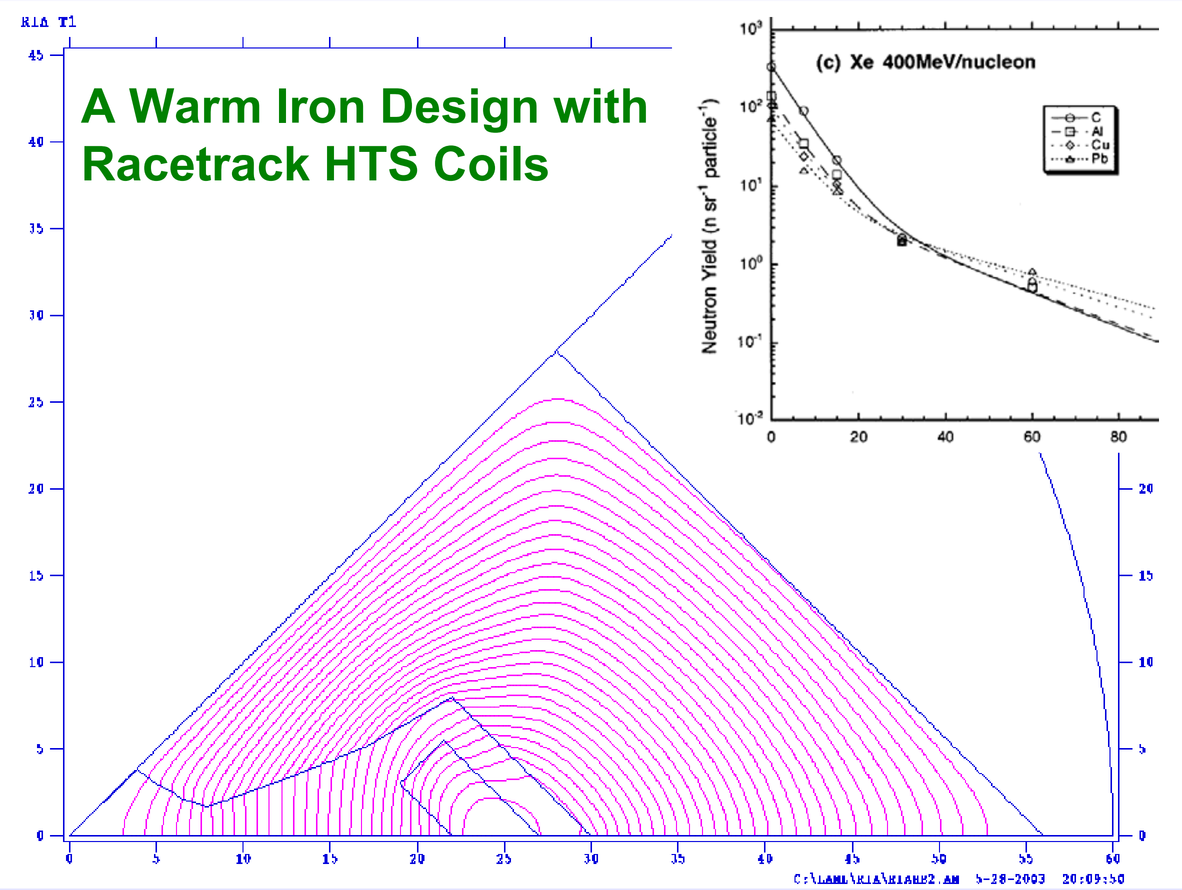
A Cold Iron Super-ferric Design with NbTi (LTS) Superconductor



Proposed Design Concept for the 1st RIA Quad in the Triplet of Fragment Separator

A Super-ferric design with yoke making significant contribution to field. Simple racetrack coils, yoke starts at R_{yoke} = 5.5 cm. Gradient = 32 T/m.

- Coils are moved further out to reduce radiation dose.
- The magnet is designed with warm iron and a compact cryostat to reduce the amount of coldmass on which the heat and radiation are deposited. This design reduces the heat load on the system by a large amount.
- Field lines are funneled to the pole to create a larger pole tip field, and gradient.

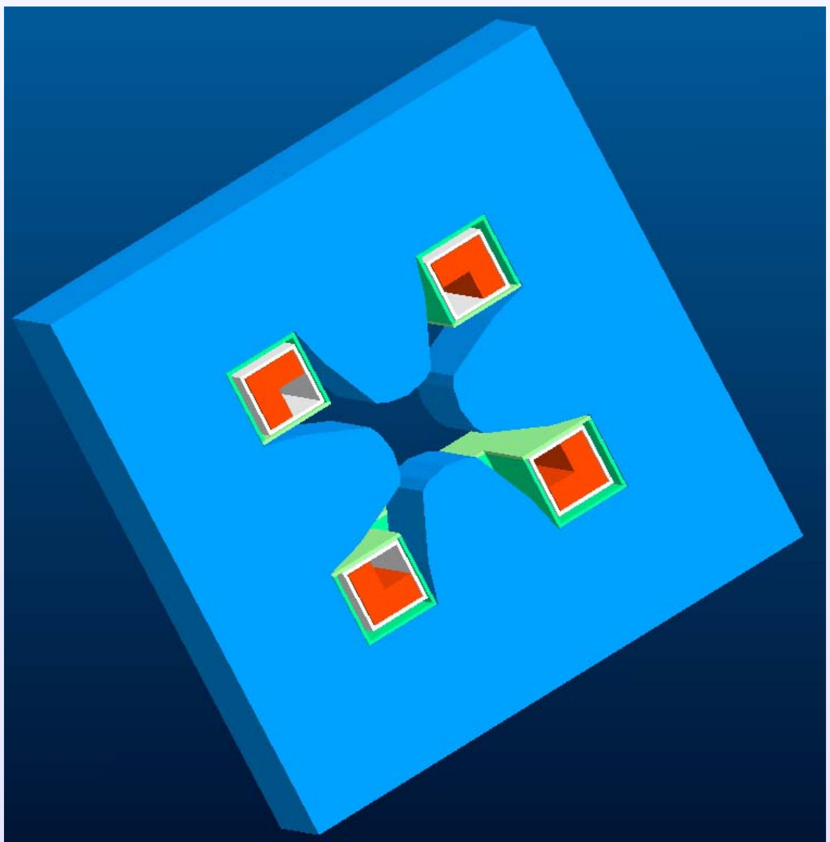


Preliminary Mechanical Concept of the Proposed Quad for RIA

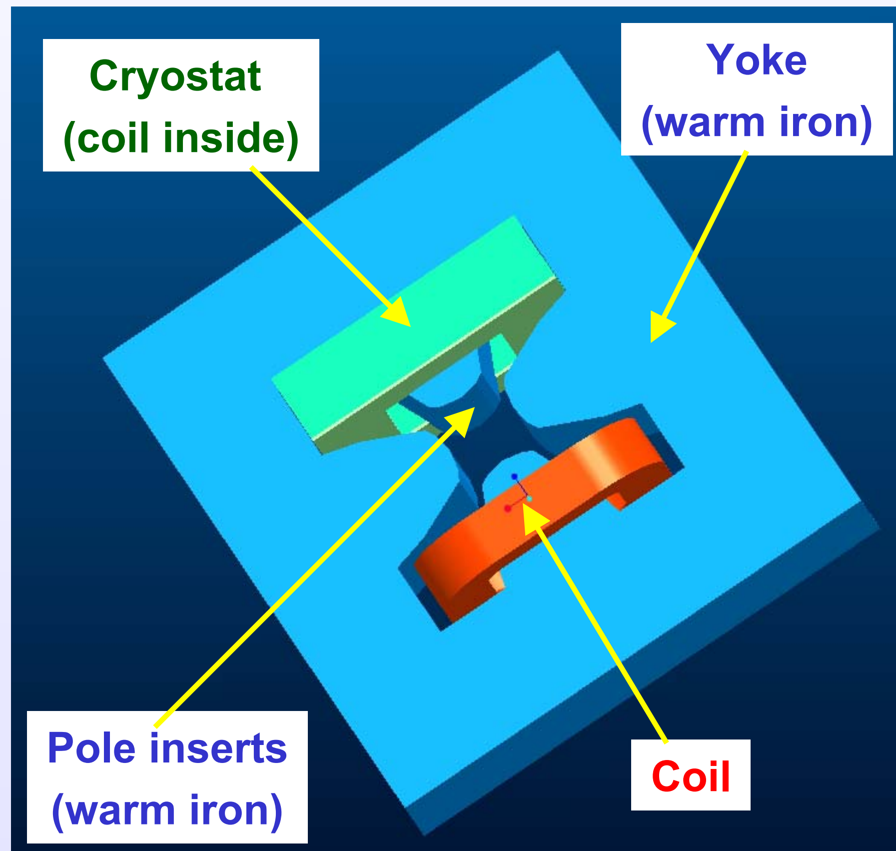
A simple warm iron super-ferric quad design with two racetrack HTS coils

Note that only a small fraction of mass is cold (see green portion), and also that it is at a large solid angle from the target .

Also two (NOT four) coils means lower heat and radiation load at the ends.



Cutout at the middle of the magnet



Coils inside the cryostat at the end of the magnet

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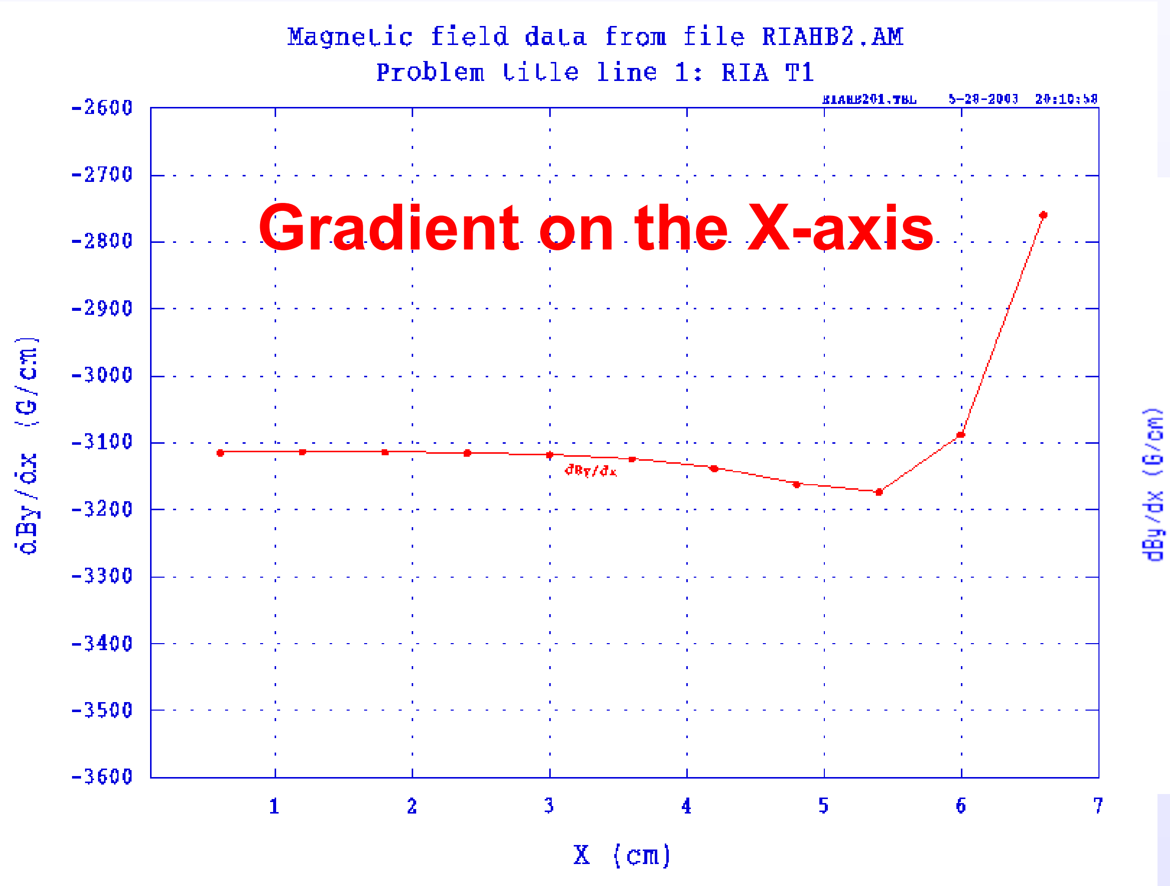
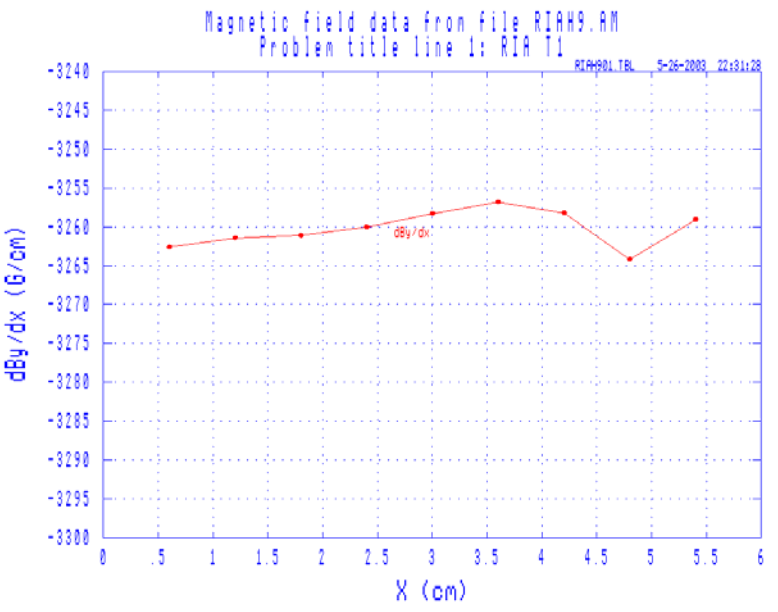
Field Quality in A Preliminary Design

The required good field aperture is 5 cm.

The required gradient is 32 T/m.





A more optimized design at one field

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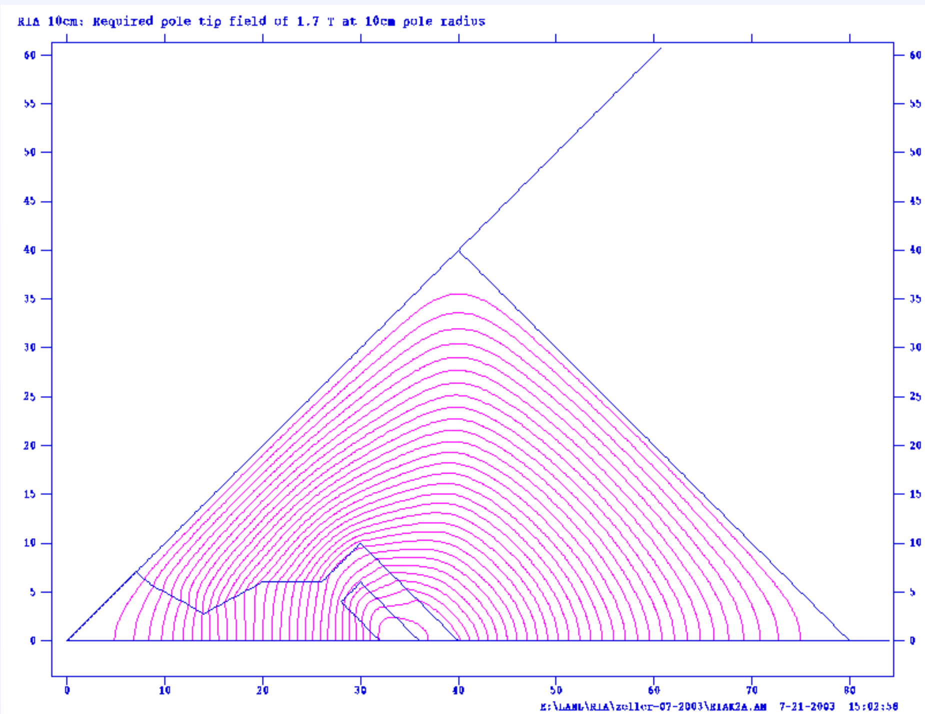
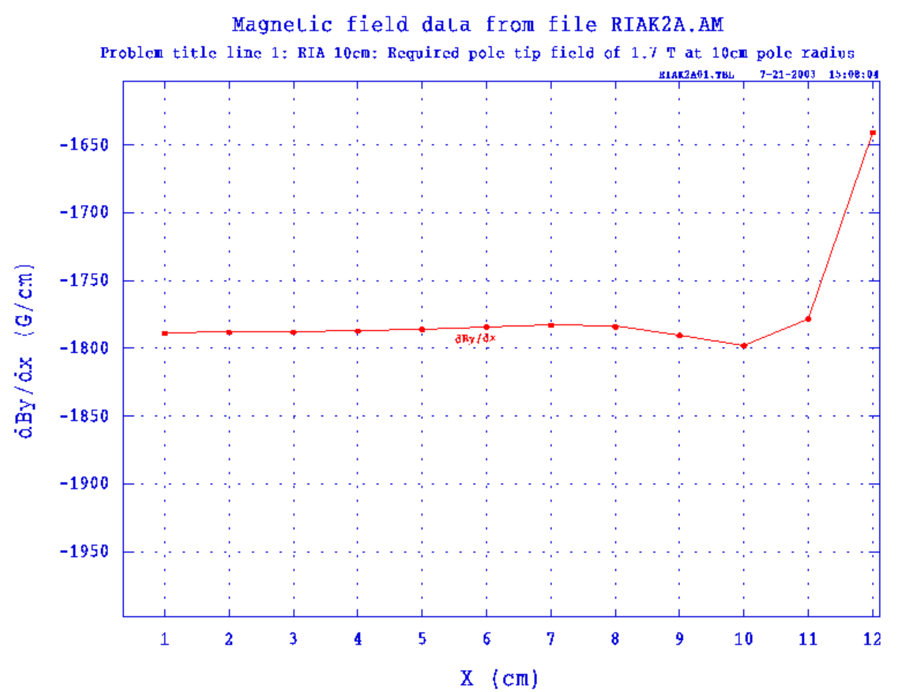
Preliminary Design of A Larger Aperture Quadrupole

Aperture: 20 cm (10 cm radius), Required Gradient : 17 T/m

(about the same pole tip field as in the smaller aperture quadrupole)





BNL/NSCL Collaboration

- BNL's experience with HTS technology for accelerator magnets is unique. BNL also has expertise in designing and building a variety of superconducting magnets. The primary responsibility of BNL is to develop designs and technologies that can satisfy both short term & long term requirements.

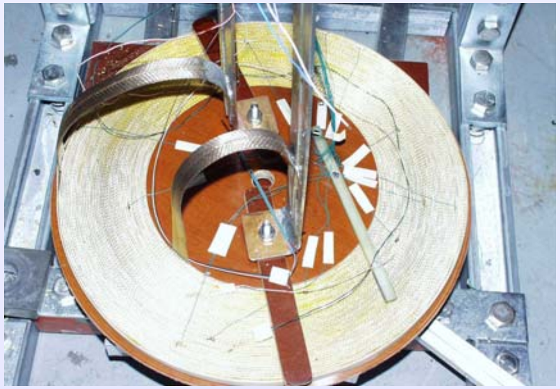
- NSCL has the knowledge of the radiation related issues and of the requirements for RIA. NSCL also has the expertise on the impact of radiation on various materials. The primary responsibility of NSCL is to carry out necessary model calculations on radiation damage and to plan experiments to assure that the magnets can withstand the required dose over the specified period of time.

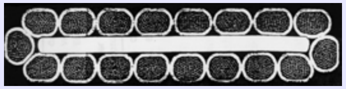
HTS Magnet R&D at BNL

NOTE:
This coil package is very similar to the one that is required for the RIA Quads.

Two HTS tape coils in common coil configuration

A coil being wound with HTS tape and insulation.





10+ kA HTS Rutherford Cable BNL/LBL/Industry collaboration

HTS tape coils at BNL

	Size, mm	Turns
Nb_3Sn	0.2 x 3.2	168
IGC	0.25 x 3.3	147
ASC	0.18 x 3.1	221
NST	0.20 x 3.2	220
VAC	0.23 x 3.4	170

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Stainless Steel Insulation in HTS Coils

Radiation damage to insulation is another major issue for magnets in high radiation area. Relatively speaking, metal (stainless steel) is an insulator. It is also highly radiation resistant. BNL has successfully tested several HTS R&D magnets and test coils made with BSCCO 2212 and BSCCO 2223 tape. A unique and very pertinent feature of these coils is the successful use of <u>stainless steel as the insulation material between turns</u>.

Two double pancake NMR coils, one with kapton insulation and the other with stainless steel.

S.S. insulation works well with superconductors

HTS Test Coil for an Accelerator Magnet

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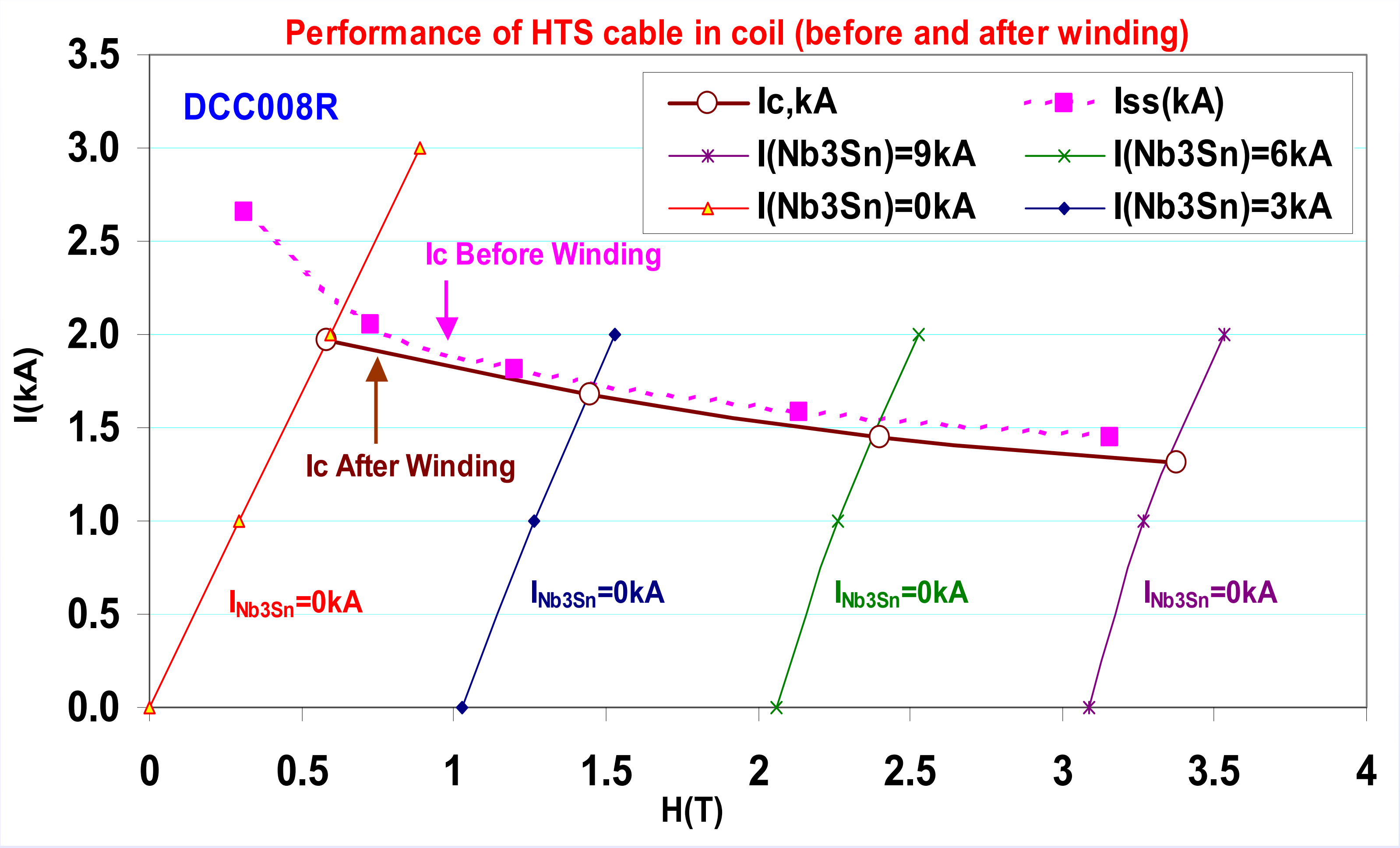
Performance of HTS Coil in the Background Field of Nb_3SN Coils



The background field on the HTS coil was varied by changing the current in "React & Wind" Nb_3Sn coils (HTS coil in the middle and Nb_3Sn on either side).

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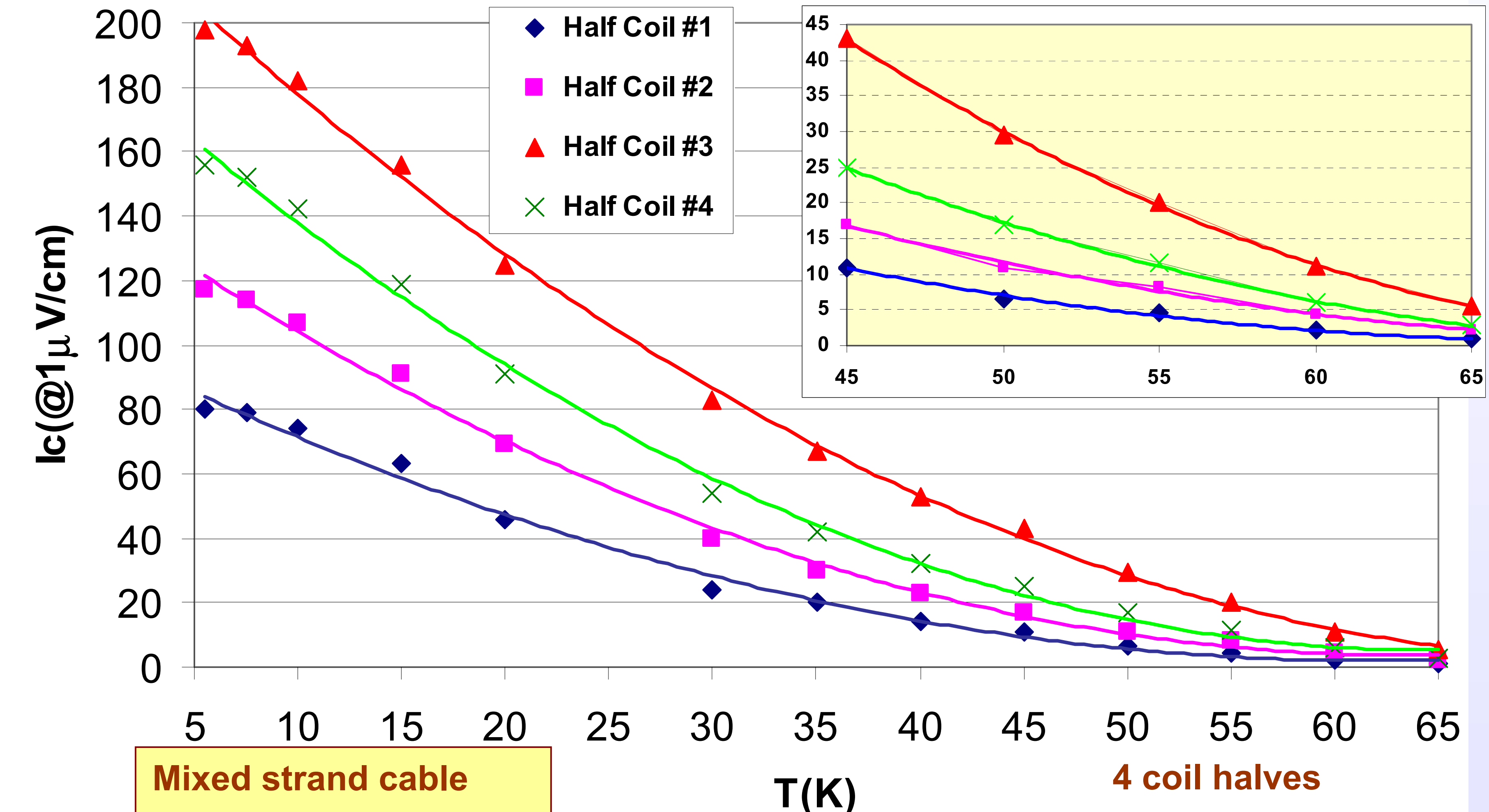
Measured Critical Current as a Function of Temperature

This temperature dependent I_c characteristic is very relevant to RIA Application.



Mixed strand cable
(2 BSCCO 2212, 16 Ag)

4 coil halves
(2 each of two coils)

Influence of Radiation Damage on HTS

Most of the literature surveyed mentions enhancement in J_c from radiation, especially at 77 K. But that is from a relatively small and controlled dose. With the amount of dose relevant to this application, J_c should go down; don't know how much - need to determine that experimentally.

S. Tönies et al. / Physica C 341–348 (2000) 1427–1430 1429

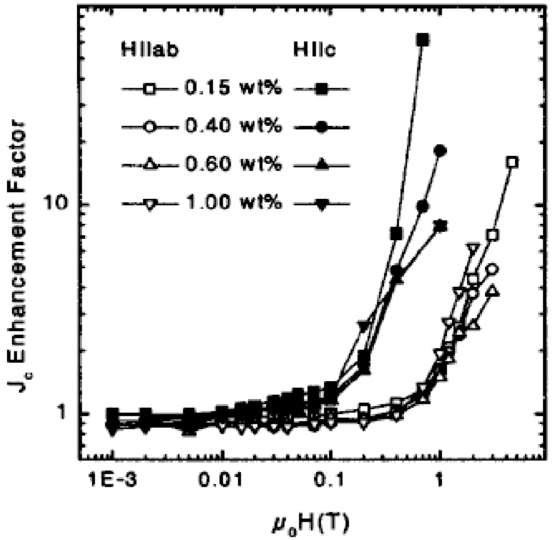


Figure 2. Enhancement of the critical current densities for samples with different amounts of uranium at 77 K, but at fixed track density.

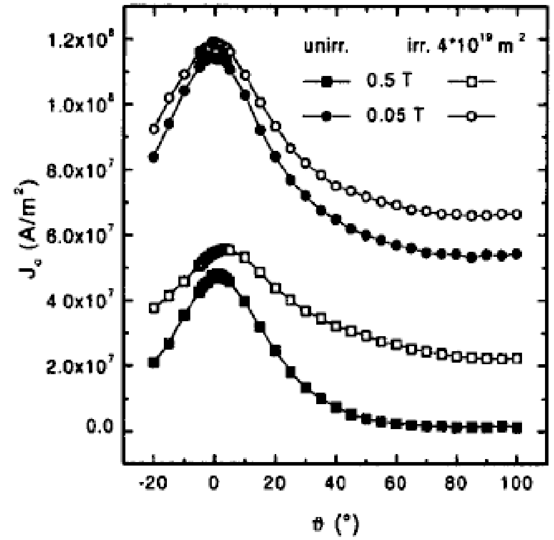


Figure 3. Anisotropy of J_c before and after irradiation to $4{*}10^{19}$ m^{-2} at 77 K and 0.5 T.

NSCL/BNL collaboration will plan experiments and do studies to determine the choice of magnet materials and the radiation load the chosen materials can tolerate.

See next talk by Al Zeller (NSCL).

R&D Topics (A Select Few)

- Develop a magnetic design that is consistent with various accelerator physics requirements. An optimum solution is likely to require a few iterations between beam physicists and magnet designers.

- Develop a warm iron design with a compact cryostat. A small cryostat significantly reduces the cryo-volume on which the heat and radiation is deposited. But a small cryostat also increase the heat leakage. An optimization is required.

- Insulation is a major concern in radiation resistant magnets. Develop and test stainless steel insulation scheme. Examine the impact of using stainless steel tape as an insulator.

- Develop HTS technology that is relevant to this specific application.

- Plan and carry out experimental studies to determine the radiation damage on HTS and other materials whose functional integrity is important to successful magnet operation in such an environment.

Summary/Status of HTS QUAD R&D for RIA's Fragment Separator Region

Apart from providing a good technical solution, this design should bring a large reduction in the operating costs.

- HTS Quads can operate at a higher temperature (20-40 K instead of 4K).
- Warm iron yoke brings a major reduction in amount of heat to be removed.
- Coils are moved outward to significantly reduce the radiation dose.
- HTS magnets can tolerate an order of magnitude higher temperature variation. Moreover, they can also tolerate large local loads or hot spots.
- Possibility of stainless steel insulation in HTS magnet is highly attractive.
- The issue of radiation damage on HTS and other material needs to be examined experimentally.
- A productive BNL/MSU collaboration in a critical area.
- Development of the concept and a few years of R&D are needed before these remarkable advantage of HTS can be fully accepted in RIA design.